

APPENDIX B

ENVIRONMENTAL RELEASES AND OCCUPATIONAL EXPOSURE ASSESSMENT: SCREEN PRINTING CTSA

Specific quantities for environmental releases and occupational exposure to chemicals can be determined for a particular system used in screen reclamation. This summary provides an overview of the releases and exposure and methodology used in determining the releases and exposure for the traditional ink remover, emulsion remover, and haze remover products.

While the greatest environmental releases and occupational exposure occur during the actual process of screen reclamation, releases and exposure also occur from volatilization from open containers, transfer operations, sampling operations, and waste rags. Air releases and the inhalation exposures occur as a result of volatilization during these operations. Releases to air occur by volatilization of chemicals from open containers, from the surface of the screen as it is being cleaned, and from rags used in the cleaning process. Estimation of releases to land and water is based on a mass balance relationship. Dermal exposures can also be estimated based on operations, formulation concentrations, and established dermal exposure models.¹

It is assumed that workers perform the following activities during each step of the screen reclamation process. Some of these steps are not necessary or are altered for certain methods assessed here. (See Figure 2-7 in Chapter 2 for an outline of the steps involved in each method.)

Step 1. Ink removal

- Open 55-gallon drum of ink remover;
- Pour ink remover into 5-gallon pail;
- Dip rag or brush into pail;
- Remove ink from screen;
- Toss rag into laundry pile; and
- Drum waste ink for disposal.

Step 2. Emulsion removal

- Open container of emulsion remover;
- Dip brush into container;
- Remove emulsion from screen; and
- Rinse screen.

Step 3. Haze removal

- Open container of haze remover;
- Dip brush into container;
- Remove haze from screen; and
- Rinse screen.

To support the assessments, numerous sources of information were used in gathering data. Preliminary information was collected from the 11-page Screen Printing Workplace Practices Questionnaire. Meetings with printers to discuss the basic data assumptions used in the assessment were held at Screen Print '93 in New Orleans in October 1993 and at the SPAI

¹ U.S. EPA. *Dermal Exposure Assessment: Principles and Applications*. Office of Health and Environmental Assessment, Jan. 1992, Document no. EPA/600/8-9/011F.

APPENDIX B

Environmental Committee Meeting in January 1994. Information was also verified through facilities participating in the Screen Printing Performance Demonstration from February to May 1994. These operation assumptions and data are presented in Table B-1.

TABLE B-1: ASSUMPTION AND DATA FROM INDUSTRY AND TRADE GROUPS		
Type of Data	Average value	
	Number	Units
Number of employees involved in ink removal	3	employees
Hours per employee per day in ink removal	1	hours
Number of employees in screen reclamation	2	employees
Hours per employee per day in screen reclamation	1.5	hours
Average number of screens cleaned per day	6	screens
Average screen size	2, 127	in ²
Size of combined screen reclamation/ink removal area	80	ft ²
Amount of ink remover per screen	8 (traditional) 4 (alternative)	oz
Amount of haze remover per screen	3.5	oz
Amount of haze remover per screen	3	oz

a) Normalized from Workplace Practices Questionnaire to remove printing establishments larger than 20 employees.

ESTIMATION METHODOLOGY

In general, in evaluating traditional and alternative screen reclamation systems, it is assumed that all releases to air, land, or water occur via the four scenarios described below. Using this assumption cleaning fluid usage has been partitioned to air, land, and water with concentrations of mass. Volatilization is estimated using a number of established models as documented below. Water and land releases are estimated to be all cleaning fluids not volatilized. The exposure/release scenarios are defined as follows:

- Scenario I. Actual screen cleaning operations. Air releases are due to volatilization of chemicals from the screen surface. Unvolatilized material is assumed to be disposed to land or water. Ink, emulsion, and haze removal for 6 screens a day; each screen is approximately 2100m².
- Scenario II. Releases to the atmosphere from pouring of 1 oz of material for sampling. This is assumed to take place over 15 minutes each day.

- Scenario III. Releases to the atmosphere from pouring of cleaning mixtures from a 55-gallon drum into a 5-gallon pail.
- Scenario IV. Releases from rags stored in a two-thirds empty drum. The water releases in this case occur in a commercial laundry. The drum is opened to add more rags once per day and to transfer the rags from the storage drum to a laundry. Rags are used only for the ink removal step.

Releases shown in the above scenarios will occur during the use of Reclamation Methods 1, 2, and 4 of Exhibit 1-2. In addition to these releases, in Method 3 (SPAI Workshop Process), an ink degradant is applied after the ink remover, followed by a water rinse; a screen degreaser is then applied prior to use of the emulsion remover. For the purposes of this assessment, Method 3 is evaluated only in conjunction with system Omicron.

Assumptions for Environmental Releases

The environmental releases model prepared for this report assumes that releases to air equal the total airborne concentration of chemicals from:

- Volatilization of solvents from screens;
- Emissions from transfer operations;
- Emissions from sampling operations; and
- Volatilization from waste dirty rags.

The following assumptions and sources of information were used in the model:

- Typical airborne concentrations;
- Typical ventilation rates;
- Emission factors from EPA (AP-42) (an EPA compendium of emission factors from the Office of Air);
- Formulation data and physical properties; and
- Average amounts of ink, haze, and emulsion remover used per site-day of 36 ounces, 21 ounces, and 18 ounces.

The model addresses releases to three media: air, water, and land. Releases to air result from volatilization from the screens during cleaning and fluid sampling and transfers. Releases for all systems studied were associated with ink removal, emulsion removal, and haze removal.

Water releases result primarily from the emulsion removal phase which is typically a rinse step using a water and sodium hypochlorite or sodium periodate solution for the traditional systems, and a water and sodium periodate solution for the alternative systems. The emulsion removal phase may also generate a contaminated rinsewater. In either phase, waste water results from screen rinsing and the spray or rag application of haze and emulsion removers.

Off-site releases to land result from the cleaning of non-disposable rags and the landfilling of disposable rags. It is assumed that rags are used only to remove the ink. The model assumes that non-disposable rags sent to a laundry contain 0.75 grams of ink remover per

APPENDIX B

18 rags. This assumption is based on:

- Limited data on how much material stays on a damp shop rag with mineral spirits;
- The average number of rags used to remove ink per screen (3 per screen); and
- The average number of screens cleaned per day (6 screens).

The model assumes weekly laundering of non-disposable shop rags and 250 days of use per year. Similarly, rags sent to a landfill are assumed to contain 0.75 grams of ink remover per 18 rags.

For systems Omicron and Beta, which have ink remover products that are water-miscible, it was assumed that nonlaunderable rags were used and the discharge to water occurred at the screen printing facility. This assumption was made given that a water rinse is used with these products in removing ink.

For aqueous solutions, the density of all components is assumed equal to 1 g/cm³. For nonaqueous solutions, ideal solution behavior is assumed and the density of each component is used to find the amount of the component in 4 ounces of ink remover.

Assumptions for Occupational Exposure

In order to estimate occupational exposure to chemicals during the screen cleaning process, an inhalation model and a dermal exposure model was developed. The assumptions underlying each model are described below.

Inhalation Model

The inhalation model used in the CTSA is a mass balance model. It assumes that the amount of a chemical in a room equals the amount leaving the room minus any generated in the room. The model is valid for estimating the displacement of vapors from containers, and the volatilization of liquids from open surfaces. Assumptions include:

- Incoming room air is contaminant-free;
- Generation and ventilation rates are constant over time;
- Room air and ventilation air mix ideally;
- Raoult's law is valid (i.e., the volatilization and interaction of vapors);
- Ideal gas law applies (i.e., the interaction of vapors);
- Inhaled doses of each chemical were based on "typical case" ventilation parameters, since these seem to give the best fit to the highest observed values (see below). Actual ventilation conditions are unknown; and
- Median values were used for the composition; worst case evaluation for air releases would include the most volatile compound at its maximum concentration.

We used the following assumptions for the frequency and duration of inhalation exposure for ink, emulsion, and haze removal:

- 6 screens cleaned per day;
- 1 to 3 workers per site;
- 3 hours per day exposure total; and
- 250 days per year.

The four scenarios described on pages B-3, 4 were modelled for assessing inhalation exposure. Inhalation exposures occur as a result of volatilization during these scenarios. The model assumes that shop workers do not wear respirators in any of the four scenarios.

Dermal Model

Dermal exposure is caused by contact with the material. Contact with the material includes touching damp rags, dipping hand(s) into a pail of ink remover, and manually applying the brush or rag to the screen to loosen the ink. Two scenarios, routine contact with two hands and routine immersion with two hands, were modelled for assessing dermal exposure. Routine contact occurs from touching rags and manually applying the brush or rag to the screen. Routine immersion occurs from dipping hand(s) into a pail of ink, haze, or emulsion remover.

Dermal contact models from the CEB handbook (CEB, 1991) were used by adjusting the concentration of the chemical in the mixture. Dermal exposure assumes no gloves or barrier creams will be used. Although exposure was estimated for the emulsion removers or haze removers containing sodium hypochlorite or sodium hydroxide, it is usually expected that use of these chemicals would result in negligible exposure given that use of these solutions without gloves causes irritation and corrosivity effects.

OVERVIEW OF METHODOLOGY

CEB (Chemical Engineering Branch) models the evaporation of chemicals from open surfaces, such as the surface of a screen, using the following model:

$$G = \frac{0.02MP}{RT} \sqrt{\frac{D_{ab} V}{\pi z}} \quad (1)$$

where:

G	=	Volatilization rate, g.m ⁻² .s ⁻¹
M	=	Molecular weight, g.mol ⁻¹
P	=	Vapor pressure, mm Hg
R	=	Gas constant, 0.0624 mmHg.m ³ .mol ⁻¹ .K ⁻¹
T	=	Temperature, K
D_{ab}	=	Diffusivity, cm ² .s ⁻¹
v_z	=	Air velocity, m.s ⁻¹
z	=	Distance along pool surface, m

The air velocity is assumed to be $v_z = 100 \text{ ft.min}^{-1}$. Since D_{ab} is not available for many of the chemicals of interest to CEB, the following estimation equation is used:

$$D_{ab} = \frac{4.09 \times 10^{-5} T^{1.9} (1/29 + 1/M)^{0.5} M^{-0.33}}{P_t} \quad (2)$$

where:

D_{ab}	=	Diffusion coefficient in air, $\text{cm}^2 \cdot \text{sec}^{-1}$
T	=	Temperature, K
M	=	Molecular weight, $\text{g} \cdot \text{mol}^{-1}$
P_t	=	Total pressure, atm

This equation is based on kinetic theory and generally gives values of D_{ab} that agree closely with experimental data. The value of G computed from eqs (1) and (2) above is used in the following mass balance expression to compute the airborne concentration in the breathing zone:

$$C_v = \frac{1.7 \times 10^5 TGA}{MQk} \quad (3)$$

where:

C_v	=	Airborne concentration, ppm
T	=	Ambient temperature, K
G	=	Vapor generation rate, $\text{g} \cdot \text{m}^{-2} \cdot \text{sec}^{-1}$
M	=	Molecular weight, $\text{g} \cdot \text{mol}^{-1}$
A	=	Area of surface, m^2
Q	=	Ventilation rate, $\text{ft}^3 \cdot \text{min}^{-1}$
k	=	Mixing factor, dimensionless

The mixing factor accounts for slow and incomplete mixing of ventilation air with room air. CEB sets this factor to 0.5 for the typical case and 0.1 for the worst case. CEB commonly uses values of the ventilation rate Q from $500 \text{ ft}^3 \cdot \text{min}^{-1}$ to $3,500 \text{ ft}^3 \cdot \text{min}^{-1}$. An effective ventilation rate of $250 \text{ ft}^3/\text{min}$ was used, which was equal to the mixing factor of 0.5 multiplied by the lowest ventilation rate ($500 \text{ ft}^3/\text{min}$). The value of C_v from equation (3) is converted to mass/volume units as follows:

$$C_m = C_v \frac{M}{V_m} \quad (4)$$

where:

C_m	=	Airborne concentration, mg.m ⁻³
C_v	=	Airborne concentration, ppm
M	=	Molecular weight, g.mol ⁻¹
V_m	=	Molar volume of an ideal gas, l.mol ⁻¹

At 25 °C, V_m has the value 24.45 l.mol⁻¹. Since a worker can be assumed to breathe about 1.25 m³ of air per hour, it is a straightforward matter to compute inhalation exposure once C_m has been determined. Equations (3) and (4) can be combined to yield the following, given the "typical case" choice of ventilation parameters:

$$I = 0.48GA t \quad (5)$$

where:

I	=	Total amount inhaled, mg.day ⁻¹
G	=	Vapor generation rate, g. m ⁻² .s ⁻¹
A	=	Area of surface, m ²
t	=	Duration of exposure, s

The advantage of equation (5) is that the quantity $GA t$ is often known beforehand, since it is equal to the total amount of the chemical released to the atmosphere. It is also useful when computing the total dose due to a sudden release of material, such as occurs when a container is opened. In this case, it is difficult to ascertain the duration of exposure, but it is a simple matter to estimate the amount of vapor in the container's headspace.

Example 1. *Estimate the vapor generation rate and worker exposure during removal of ink from a printing screen using 100 percent toluene. The worker cleans screens for 1 hour each day in a room with a ventilation rate of 3,000 ft³. min⁻¹. The screen area is 2,217 in². Assume a mixing factor of $k = 0.5$.*

Toluene has the following physical properties:

Molecular weight:	92.14 g. mol ⁻¹
Vapor pressure:	28 mmHg at 25 °C
Diffusion coefficient:	0.076 cm ² .sec ⁻¹

Using these values in equation (1) gives:

Generation rate G :	0.28 g.s ⁻¹ .m ⁻²
Airborne concentration:	141 ppm (C_v)
	534 mg.m ⁻³ (C_m)
Exposure over 1 hour:	667 mg

APPENDIX B

If the CEB worst-case parameters are used in equation (2), i.e., a mixing factor of $k = 0.1$ and a ventilation rate of $500 \text{ ft}^3 \cdot \text{min}^{-1}$, then the estimated airborne concentration is $C_v = 4,216 \text{ ppm}$. Exposures and volatilization rates are calculated by multiplying the pure-component values from Exhibit 4 by the mole fraction of that component in the liquid phase. A typical screen has an area of $2127 \text{ in}^2 = 1.37 \text{ m}^2$. Each worker cleans screens for 1 hour per day. Amounts released should be checked against amount used to ensure mass balance.

Example 2. *If a worker cleans 6 screens using 8 oz/screen of mineral spirits, the amount of spirits used will be:*

$$6 \times 8 \times 29.57 \text{ fluid oz/cc} \times 0.78 \text{ g/cc} = 1107 \text{ g}$$

The amount volatilized will be:

$$0.01087 \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \times 3600 \text{ s} \times 1.37 \text{ m}^2 = 53 \text{ g}$$

Thus, the amount volatilized is not limited by the amount used. For the case of the traditional haze remover, however, volatilization is limited by the amount used. If 3 oz of haze remover containing 30 wt percent (32 volume percent or 21 mole percent) acetone is used per screen, the total amount available is:

$$6 \times 3 \times 0.32 \times 29.57 \text{ fluid oz/cc} \times 0.79 = 133 \text{ g}$$

The amount that would volatilize over 1 hour is:

$$1.49 \times 1.37 \times 3600 \text{ s} = 7,350 \text{ g}$$

UNCERTAINTIES

Occupational Exposure: Uncertainties

Determining occupational exposure levels associated with screen cleaning requires making assumptions about the cleaning process, the workplace environment, health and safety practices, and waste management practices. This section describes the uncertainties involved in assessing occupational exposure for screen cleaning. It also explains the assumptions underlying the exposure assessment model developed for the CTSA.

EPA has published Guidelines for Exposure Assessment in the Federal Register. These are guidelines for the basic terminology and principles by which the Agency is to conduct exposure assessments. There are several important issues relevant to this assessment. If the methodology is one which allows the assessor to in some way quantify the spectrum of exposure, then the assessor should assess typical exposures, as well as high end exposures or bounding exposures. Typical exposures refer to exactly that, how much the typical person is exposed to the particular substance in question. High end refers to a person exposed to amounts higher than 90

percent of the people (or ecological species of interest) exposed to the substance. Bounding estimates are judgements assuming that no one will be exposed to amounts higher than that calculated amount. However, in many cases, all we can do is give a picture of what the exposure would be under a given set of circumstances, without characterizing the probability of these circumstances actually occurring. These are called "What if" scenarios. They do not try to judge where on the exposure scale the estimate actually falls. All of the exposure assessments fall into the "What if" category for this assessment.

Although the screen cleaning process is relatively straightforward, occupational exposure levels will differ in actual shop environments because of many variables such as variations in:

- Toxicity of the chemicals used;
- Amount of chemicals applied;
- How the chemicals are applied;
- Compliance with health and safety and waste management procedures;
- Equipment operating time;
- Ventilation conditions and shop lay-out; and
- Temperature conditions (ambient and solvent).

All of these variables will influence the impacts of chemicals used in the screen cleaning process on shop workers. Based on studies of screen printing operations conducted by the National Institute for Occupational Safety and Health (NIOSH), it appears that many of the small to medium sized operations do not follow health and safety precautions.² Specifically, workers were observed performing screen reclamation without protective gloves or proper breathing apparatus. Nor did shop workers wear protective aprons to reduce dermal exposure. According to one study, some workers used solvent to wash their arms and hands after completing the screen cleaning process. In another study, rags and paper towels contaminated with solvent were placed in an open trash can. Both of these practices will also increase exposure levels significantly.

There are also differences in how screen printers wash the screens; this affects occupational exposure. Some shops use automated screen washers which blast the screens with solvent or hot water in an enclosed system. Others use a hose in a sink to flush the screens by hand or the cleaner is spread on the screen by hand, and the worker uses a rag or paper towel to wipe down the screen. Exposure levels will differ if individual workers use more (or less) cleaner than specified, and if they allow it to remain on the screen longer than specified.

During research to support this assessment a NIOSH Health Hazard Evaluation (HHE) document on screen washing was located and used to validate exposure estimates. CEB initially estimated occupational exposures by applying the relatively conservative models that are normally used for review of new chemicals. The resulting exposure estimates were high in comparison to actual monitoring data. These data indicated that, after necessary corrections were

² Sources: Health Hazard Evaluation Report No. HETA 84-299-1543, (Chicago, IL: Impressions Handprinters). Health Hazard Evaluation Report No. HETA 81-3 83- I 151, (Chicago, IL: Main Post Office).

made, the exposures predicted by the CEB model were within the range of the NIOSH observations, as long as the "typical case" ventilation parameters were chosen. Use of the "worst case" ventilation parameters in the CEB model leads to results that exceed the range of the experimental data by about an order of magnitude. The theoretical basis of the CEB model was investigated and a standard engineering formula for mass transfer in laminar boundary layers was found to provide a closer approximation to the upper end of NIOSH data when used with the same "worst case" ventilation parameters.

Both the CEB model (when used with the "typical case" ventilation parameters) and the boundary-layer approach can provide estimates of inhalation exposures which agree with the experimental data within one order of magnitude or better. It is difficult to obtain better agreement than this without knowing a great deal more about each exposure scenario, such as the details of the screen cleaning process at each site, the solvent temperature, the air temperature, and the ventilation pattern in the screen cleaning area. These items are not routinely recorded by NIOSH investigative teams.

Dermal Exposure Model

The dermal exposure model is based on the concentration of material contacting the skin and the surface area contacted. Dermal exposure levels will differ in actual shop environments because of many variables such as variations in:

- Type of worker activity;
- Likelihood or type of contact (i.e., routine or immersion);
- Frequency of contact (i.e., routine or incidental);
- Potential surface area contacted;
- Likelihood and effectiveness of protective equipment being used;
- Amount of chemical remaining on the skin; and
- Evaporation rate of the chemical.

In estimating dermal exposure, it was assumed that gloves were not worn. However, assuming that gloves are worn, dermal exposure is assumed to be negligible to none depending on the chemical in question. In situations where the chemical is corrosive (e.g., sodium hypochlorite), dermal exposure to shop workers using gloves is zero. The model assumes that one hand (surface area 650 cm²) is routinely exposed during the screen cleaning process (1 to 3 mg/cm² typically remaining on the skin).³

Environmental Releases: Uncertainties

Determining environmental releases associated with screen cleaning requires making assumptions about the cleaning process, the workplace environment, and waste management practices. This section describes the uncertainties involved in assessing environmental releases associated with screen cleaning. It also explains the assumptions underlying the environmental

³ Source: U.S. Environmental Protection Agency, *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments*, (February 28, 1991), p. 4-36.

release assessment model developed for the CTSA.

Uncertainties

Uncertainties related to environmental releases overlap with the uncertainties associated with occupational exposure. They include variations in:

- Toxicity of the chemicals used;
- Amount of chemicals applied;
- How the chemicals are applied;
- Compliance with waste management procedures;
- Equipment operating time;
- Ventilation conditions and shop lay-out; and
- Temperature conditions (ambient and solvent).

RELEASE AMOUNTS VS. OCCUPATIONAL EXPOSURES

Air releases were computed in two different ways, depending on the particular scenario under consideration. For Scenario I (evaporation from a screen) and Scenario II (evaporation during sampling), the equations used for computing the total mass of material volatilized can be condensed into the following expression:

$$GA_t = \frac{8.24 \times 10^{-8} M^{0.835} P \left(\frac{1}{29} + \frac{1}{M} \right)^{0.25} v_z^{0.5} A t}{T^{0.05} z^{0.5} P_t^{0.5}} \quad (6)$$

where:

GA_t	=	Mass released (= flux x area x time)
M	=	Molecular weight (g.mol ⁻¹)
P	=	Vapor pressure (mmHg)
v_z	=	Air velocity (ft.min ⁻¹)
A	=	Area of surface (cm ²)
t	=	Duration of release (s)
T	=	Air temperature (K)
z	=	Length of surface (cm)
P_t	=	Total pressure (atm)

For all cases of interest here, the temperature T , total pressure P_t , and air velocity v_z are assigned fixed values. These are 298 K, 1 atmosphere, and 100 ft.min⁻¹, respectively. In addition, the surface is taken to be square, so that $z = A^{0.5}$. Thus, the mass of material released has the following dependencies:

$$GA_{t_{dc}} M^{0.835} \left(\frac{1}{29} + \frac{1}{M} \right)^{0.25} \quad (7)$$

$$GA_{t_{dc}} P \quad (8)$$

$$QA_{t_{dc}} A^{0.75} \quad (9)$$

For Scenario III (releases from pouring) and Scenario IV (releases from drum of rags), the vapor space of the container was assumed to be saturated. The model used can be represented

$$QA_t = \frac{MPV}{(24.45)(760)} \quad (10)$$

where:

M	=	Molecular weight (g.mol ⁻¹)
P	=	Vapor pressure (mmHg)
V	=	Volume of container (l)

For each scenario, the container volume is fixed, so that:

$$QA_{t_{dc}} M \quad (11)$$

$$QA_{t_{dc}} P \quad (12)$$

Releases to water and/or land disposal are computed by a mass balance approach; any chemical not volatilized is assumed to be disposed to one of these two media.

The amount of each chemical inhaled by workers is given by the following expression:

$$I = \frac{719}{Qk} GA_t \quad (13)$$

where:

I	=	Inhaled dose (mg.day ⁻¹)
Q	=	Ventilation rate (ft ³ .min ⁻¹)
k	=	Mixing factor (dimensionless)

In this report, Q is fixed at $3,000 \text{ ft}^3 \cdot \text{min}^{-1}$ and $k = 0.5$. Thus,

$$I = 0.48 GA t \quad (14)$$

Thus, the inhaled dose has the same dependencies as the amount released, no additional variables being introduced.

Based on the above expressions, the amount released to the atmosphere in Scenarios I and II is approximately proportional to $M^{0.835}P$. For Scenario III and IV, the dependence is approximately MP . The vapor pressure is generally lower for compounds with higher molecular weights. An idea of the sensitivity of vapor pressure to molecular weight can be obtained from a molecular model of the liquid state. According to Fowler and Guggenheim (*Statistical Thermodynamics*, Cambridge, 1956), for a liquid whose intermolecular potential energy can be represented by the Lennard-Jones function:

$$U(r) = 4\epsilon \left[\left(\frac{\sigma}{r} \right)^6 - \left(\frac{\sigma}{r} \right)^{12} \right] \quad (15)$$

the vapor pressure can be estimated to be:

$$p = 1158 \frac{\epsilon}{\sigma^3} e^{-8.136(\epsilon/kT)} \quad (16)$$

As noted in the development of an expression for D_{ab} , the diffusivity, in Appendix K of the CEB Manual, the quantities ϵ and σ can be roughly correlated with molecular weight. When these parameters are regressed against experimental data for C_1 - C_9 and substituted into the expression for vapor pressure, a relationship of the following form is observed:

$$p_{vc} M^{0.23} e^{-M^{0.51}} \quad (17)$$

Somewhat different dependencies will be found with different sets of experimental data, but all of the resulting expressions will show that vapor pressure falls off rapidly with molecular weight within a homologous series of compounds. Thus, the amount of chemical volatilized and the resulting inhaled dose will be approximately proportional to:

$$M^{0.69} e^{-M^{0.51}} \quad (18)$$

